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HYBLA FAIR EVENT: ENVIRONMENTAL REPORT

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W.L. Russell, Jr.

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were made

Abstract

We made a series of environmental measurements during the Hybla Fair nuclear event. Experimenters were unsure of conditions that would be created since there was no closure system and the experiments were close to the source. We tested a variety of temperature, pressure, and load devices. The results will aid in the design and engineering of future close-in diagnostic packages and pipes.

Introduction

During the Hybla Fair nuclear event, L-Division at LLL was interested in finding out what the pipe environment was and if the diagnostic packages would survive the environment. They asked the Field Operations Group, Engineering Measurements Section of the Material Engineering Division, to design and field environmental measurements. Due to the closeness to the source and lack of closure system, a possible failure or survival problem in the scientific experiments was anticipated. Experienced personnel felt that a proposed total fluence calorimeter (SLC) experiment would be destroyed and thus did not use it. It was felt that the thermopile fluorescer (TPF) experiment that was used might fail. We wanted to know what kind of environment the TPF would survive or fail in. Thus, environmental tests were performed to gather data to aid in the design and engineering of future close-in diagnostic packages and pipes.

Available electronics limited us to 31 channels. The areas of interest were the temperature and pressure inside the pipe, acceleration of the pipe, the incident energy deposited into the collimators, the induced shock in the pipe in the diagnostics area and on both sides of the slip joint, and the pipe movement or displacement into the grout plug. Eight temperature, ten load, three accelerometer, and eight pressure measurements were made. A detailed description of each type follows.

Temperature

DESCRIPTION AND PURPOSE

Eight thermocouples were chosen to provide a complete temperature versus time profile. They were designated T1, T2, etc.

Three different configurations of tungsten versus tungsten-rhenium

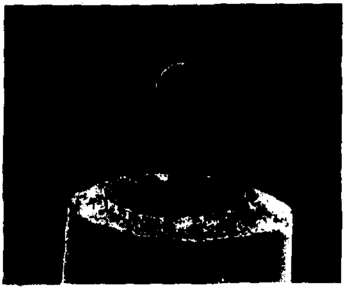

Fig. 1. Exposed tip thermocouple bead at 200X.

thermocouples were used. *Tungsten versus* tungsten-rhenium is calibrated to a maximum temperature of 2 316°C. Since its melting point is approximately 3 000°C, it is useful to a higher temperature than the calibrated value.

T1, T2, and T3 were Baldwin, Lima, and Hamilton Corporation (BLH) micro-miniature thermocouples with 25-μm-diam wire in an exposed tip configuration mounted in a 0.35-mm-diam tantalum sheath (see Fig. 1). The wires are insulated with a fused ceramic tube. This type of junction will give the fastest rise time because of the small mass of the junction bead. The thermocouples are extremely fragile.

T4, T6, and T7 were similar BLH micro-miniature thermocouples. However, the 0.35-mm-diam tantalum sheath is formed into a flat tip configuration with the junction enclosed in the flat portion and grounded. Because of the larger mass of the sheath in contact with the junction, this thermocouple responds slower than the exposed tip type.

T5 and T8 were regular sheath-type thermocouples from Omega Engineering, Inc. The thermocouple wire was 0.2-mm-diam tungsten 5% rhenium versus tungsten 26% rhenium enclosed in a 1-mm-diam tantalum sheath. The junction was enclosed but ungrounded. Insulation was MgO. Because of the large mass of the wire and junction area, the response time is slow.

As noted, various types of thermocouples were used to establish a complete temperature versus time profile. We expected that the 25-μm exposed tip junctions would respond fast and measure time of arrival plus a temperature rise profile but would probably fail after a short duration. We connected these three thermocouples to electronics channels with increased sampling rates for better frequency response. The flat tip was designed to give us the medium response and would probably remain undamaged. It would fill in the middle portion of the temperature profile. The rugged 0.2-mm type would respond slowly but would last through the complete event. Figure 2 shows thermocouple locations along the pipe.

The upper band edge was set to 40 mV, equivalent to approximately 2 300°C. This setting allowed full use of the calibrated scale and kept the measurements within the predicted range.

RESULTS AND CONCLUSIONS

Seven thermocouples out of eight functioned as expected, except all

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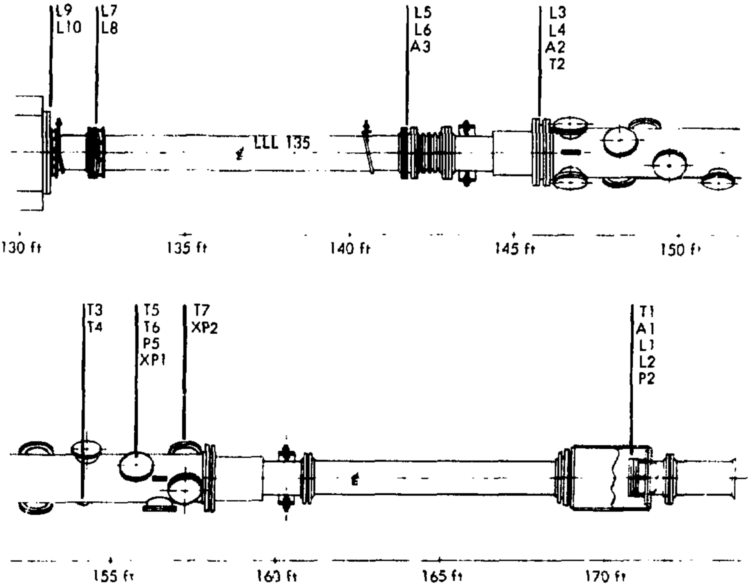

Fig. 2. Instrumentation locations on line-of-sight (LOS) pipe.

channels went to band edge, meaning the temperature went over 2 300°C. T1, T2, and T3 responded very fast with arrival time of T1 later than T2 and T3, because it was farther down the pipe. The distance between T1 and T2 is 7.92 m and the difference in arrival time was 2.5 ms. Accepting trace timing, the implied velocity in the pipe is about 3 km/s. The fast-responding thermocouples functioned to measure temperature as well as time of arrival. Data is shown in Fig. 3 (black and green curves).

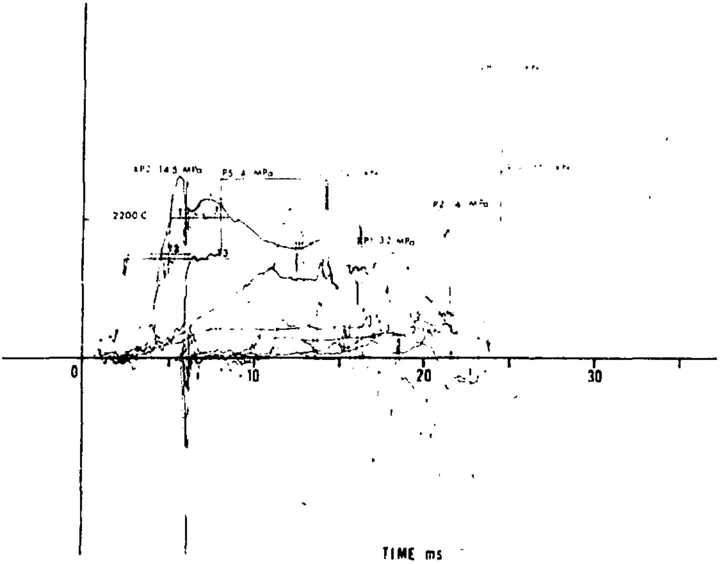

Fig. 3. Data summary—black, exposed-tip thermocouples; green, enclosed-tip thermocouples; yellow, foil strain-gaged load cells; red, semiconductor load cells; and violet, pressure transducers.

Load Cells and Load Rings

DESCRIPTION AND PURPOSE

Three different types of load measurements were made: first, the incident energy deposited in the Time Resolved Crystal Spectrometer (TRCS) collimator; second, the shock wave in the pipe before and after being decoupled by the bellows and slip joint; and third, the pipe loading relative to the concrete bulkhead. These measurements were made using three different arrangements of strain-gaged load cells. Time of arrival, as well as location, clearly separate each one. To obtain some degree of dynamic range, we chose two different types of strain gages at each location. The odd-numbered L's are metal-foil type, Micro-Measurements EA-13-125AC-350 strain gages, and the even-numbered L's are semiconductor BLH-SPB2-20-35 strain gages. The semiconductor gages have a greater sensitivity than the foil gages, with gage factors of 120 and 2, respectively.

L1 and L2 were the load cells used to measure the incident energy deposited on the TRCS collimator: L1 is a foil type and L2 is a semiconductor type. Refer to Fig. 2 for location and Figs. 4 and 5 for assembly information The distance from the working point is 51 m.

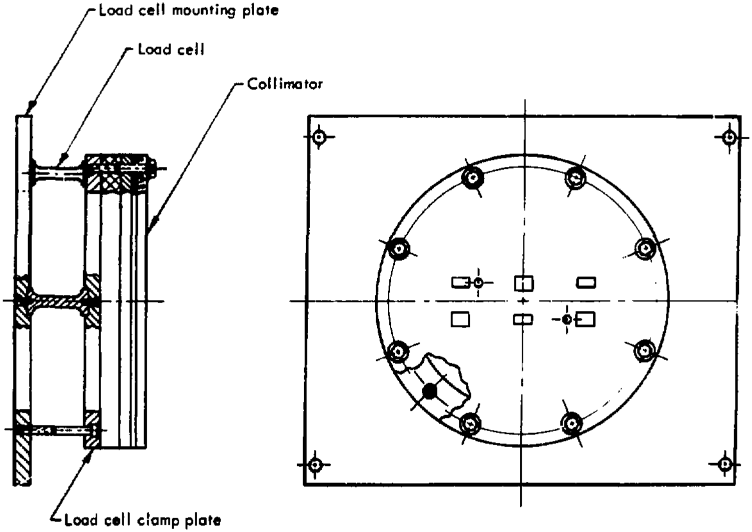

Fig. 4. TRCS collimator assembly.

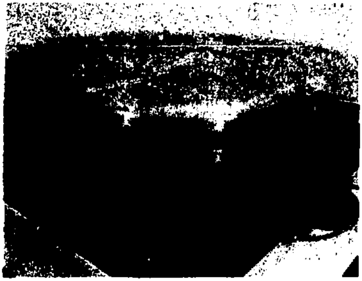

Fig. 5. Load cells on collimator.

L3-L4 and L5-L6 load rings are in series with the pipe. L3 and L4 are downstream from the bellows and slip joint with L5 and L6 upstream. These load rings measured the effectiveness of the slip joint and bellows in decoupling the shock wave down the pipe into the TPF experiment. The load ring assembly is shown in Figs. 6 and 7 and their locations on the pipe are shown in Fig. 2. L3 and L5 are foil-type strain gages and L4 and L6 are semiconductors (refer to Fig. 8 for gage locations).

L7-L8 and L9-L10 are not in series with the pipe but mounted externally on pipe flanges and bearing against a concrete bulkhead approximately 3.66 m thick. These load cells measured pipe movement into the concrete.

The original bulkhead was designed for a sand fill, as were the load cells, but a late field change called for poured concrete. Since the load cells were already installed, this change could cause the following problems: one, the loads would probably be higher than design loads due to the firmer bearing surface of the concrete; and two, there was a possibility of grounding problems when the load cells were buried in the wet concrete. Refer to Fig. 2 for location on the pipe and Figs. 9 and 10 for assembly and installation.

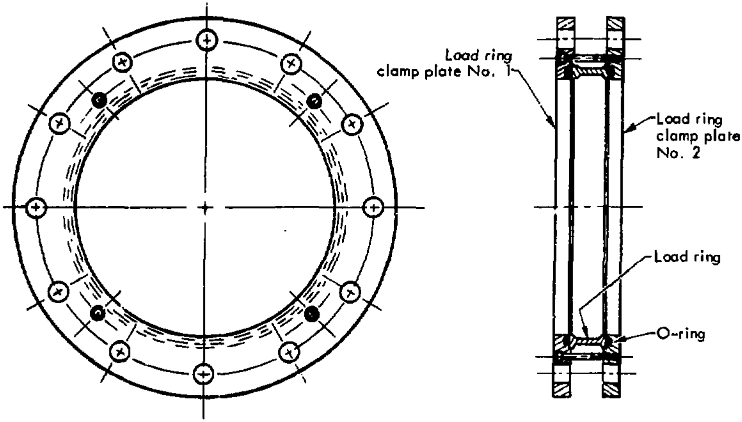

Fig. 6. In-series load ring.

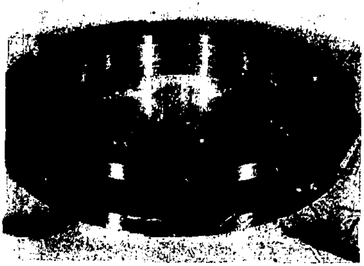

Fig. 7. Photo of in-series load ring.

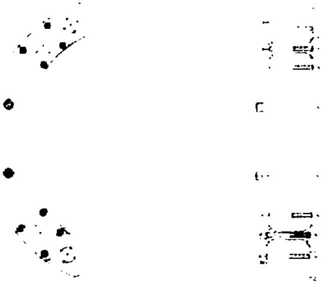

Fig. 9. Load cell assembly.

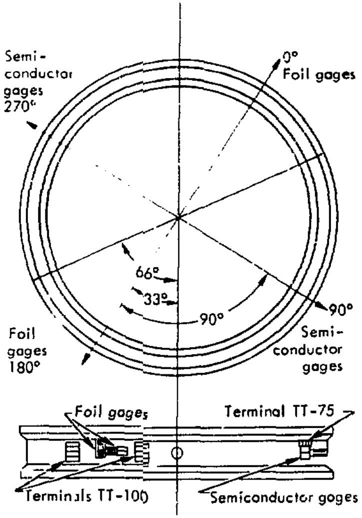

Fig. 8. In-series load-ring strain-gage locations.

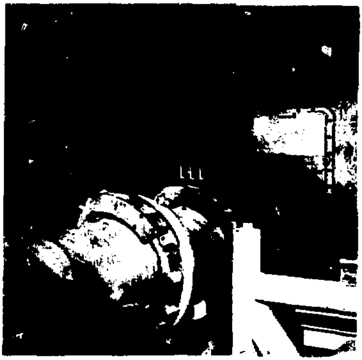

Fig. 10. Load cell installation.

RESULTS AND CONCLUSIONS

All 10 load channels functioned properly and we recorded data. Pair 1.1 and 1.2 responded first and very sharply with 1.2 going to band edge because of its high sensitivity and 1.1 recording within its calibrated range. The two pulses correspond in time as shown by the yellow and red curves on Fig. 3. The sharp rise time of the pulses indicates the high rate of energy deposition in the TRCS collimator. The force per unit area is 2.6 MPa over the exposed area of the collimator. The two channels responded as predicted.

Pairs 1.3-1.4 and 1.5-1.6 show that the slip joint did indeed make a discontinuity in the shock wave coming down the pipe. The load on the TPF experiment on the downstream side was approximately 5.5X less than the load upstream from the slip joint and bellows. This information should be of interest to people designing diagnostic packages. The semiconductor channels L4 and L6 gave the best resolution because of their high sensitivity, although L3 and L5 did correspond in time and amplitude. L3 and L5 signals were approximately 1 mV with about 0.5 mV noise, therefore, not so clean. This information is of particular interest because neither the semiconductor nor the foil gages went to band edge so a valid comparison can be made between the two traces. They correspond extremely well. Accepting L5-L6 trace timing, pipe shock velocity is about 2 km/s.

Pairs L7-L8 and L9-L10 measured the force of the pipe moving into the concrete wall, but three out of the four measurements went to band edge. L7, a foil gage of low sensitivity, did give us a total load measurement at that station. L9 and L10 were expected to see the greatest load and based on the load values at band edge, they were higher than L7 and L8. We feel that had sand been used instead of concrete our measured levels probably would have been within the levels set.

To get an overall comparison of the load measurement, refer to Fig. 3 (red and yellow curves). Accepting L7 trace timing, ground shock velocity was about 1 500 m/s.

Accelerometers

DESCRIPTION AND PURPOSE

Only three accelerometers were used. A1 was on the rear of the TRCS collimator, A2 was downstream from the slip joint and bellows in the same area as L3 and L4, and A3 was ahead of the slip rings and bellows in the area of L5 and L6 (refer to Fig. 2). The accelerometers were the conventional, Statham, unbonded, strain-gage type. A1 and A2 were ±100 g range and A3 was a ±1000 g range. A1 was used to measure the TRCS collimator acceleration, which was compared with the time of arrival and amplitude measured by L1 and L2.

A2 and A3 were used to measure the difference in acceleration through the slip joint area and to compare the decoupling factor with that of the load measurements in the same area. Refer to Fig. 2.

RESULTS AND CONCLUSIONS

A1 functioned properly for positive excursions. Since the negative band edge was set at zero, none of the negative portions of the signal were recorded. Correlation was not apparent. A2 and A3 did measure a differential acceleration decoupling factor of 7X across the slip joint and bellows area. Since acceleration is frequency sensitive and the input wave form must certainly have broadened across the slip joint and bellows, we believe this data correlates very closely with the 5.5X decoupling factor measured by the load rings across the same section of the pipe. Refer to Figs. 11-13.

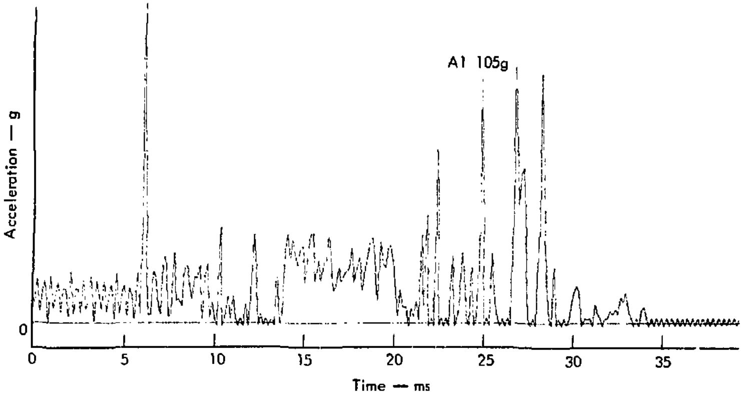

Fig. 11. A1 accelerometer data.

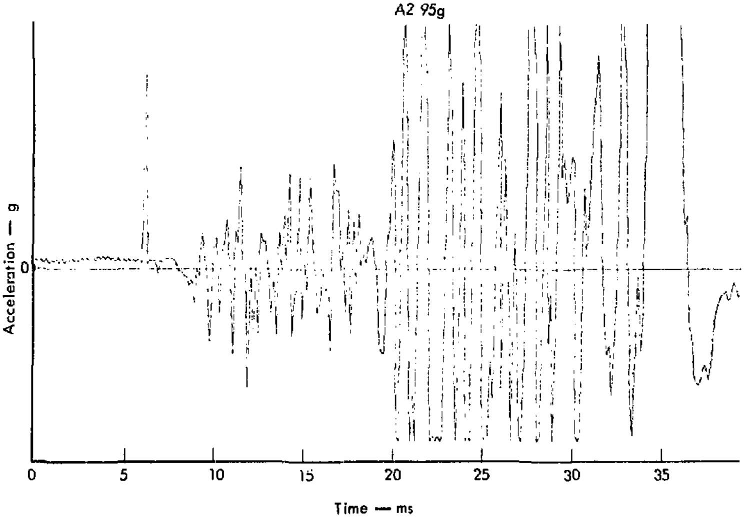

Fig. 12. A2 accelerometer data.

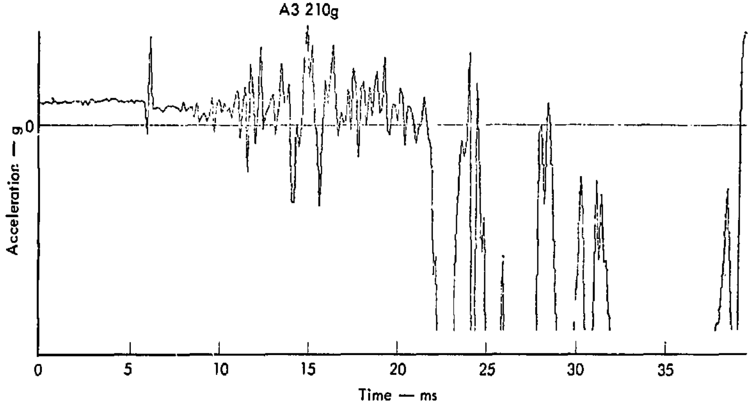

Fig. 13. A3 accelerometer data.

Pressure Transducers

DESCRIPTION AND PURPOSE

In this part of the test, we wanted to measure the pressure inside the pipe at the TPF and SLC box using different types of conventional commercial transducers, plus two others of an experimental Engineering Measurement Section (EMS) design. Because of the high temperature and shock predicted, it was difficult to select transducers from our available stock or purchase on short notice transducers that would withstand the environment. This gave us the opportunity to make some evaluations of the transducers needed for this type of close-in testing. Cooled diaphragm transducers were not feasible because of the additional cost and plumbing required.

We chose, because of the availability, to use four Precision Sensors, two Kulites, and two of the EMS experimental type. The Kulites were a semiconductor type and the Precision Sensors were a bonded, metal-foil, strain-gage type. The EMS experimental type used semiconductor strain gages bonded directly to the diaphragm using the diaphragm as the heat shield. Several materials offer suitable mechanical properties for pressure diaphragms for use at the expected pressures. If we look at Vascomax 300, for example, a suitable thickness of material is about 1.2-1.5 mm. The time required for this material to equilibrate after a step temperature input is of the order of 100-150 ms. The design of XP-1 and XP-2 assumes that the first 15-20% of that time gives us useful data. The development of this idea and earlier experimental data are the subject of Ref. 1.

P1 was a 0.6-MPa Kulite located in the SLC box and P2 was a 6-MPa Precise Sensor instrument. The two different pressure ratings were selected to cover the possible dynamic range. P3, P4, P5, and P6 were located at various ports in the TPF pipe. P3 was a 0.6-Mpa Kulite, P4 was a 6-MPa Precise Sensor, P5 was a 3-MPa Precise Sensor, and P6 was a 100-MPa Precise Sensor. XP1 and XP2 were located in the rear of the TPF pipe. Both were designed for a range of 6 MPa and statically calibrated over that range.

RESULTS AND CONCLUSIONS

Four of the eight pressure channels failed. There was recorded information for all eight channels, but only four channels had useful data.

P1 and P3 went negative at zero time because the extremely high temperature relaxed the preload on the diaphragm. The recovery time was too slow to record any useful data, although they appear to have survived for at least 200 ms. Since the recorded pressure was over 3 MPa, both transducers were drastically overranged.

P2, located in the SLC box, indicated 4 MPa and a time of arrival of 17 ms, somewhat slower than the other three channels because it was located about 7.92 m farther downstream in the pipe.

P4, located in the TPF package, went negative at zero time due to the relaxation of the diaphragm because of the extremely high temperature. It also appeared to lose electrical integrity and, we believe, should be considered a complete failure.

P5 went to band edge at 4 MPa, but recovered at about 24 ms and continued to function out to 200 ms. The shape of trace at approximately 6 ms indicates it might have suffered some damage from shock.

P6 was intended to cover a disastrous overpressure in the pipe. It failed at zero time and never recovered. It could have been destroyed by the electromagnetic pulse or possibly a negative zero shift in the electronics could have occurred.

XP1 functioned properly over its useful time range of approximately 20 ms. Since an uncooled flush diaphragm is exposed to an elevated temperature pulse as well as a pressure pulse and in this case thermal strain cannot be balanced out, we ignore the trace after a finite time period. We believe this trace indicates survival to at least 200 ms and clearly shows thermal effect on the strain gages as well as good correlation with P2 and P5.

XP2 lasted to approximately 15 ms and failed electrically. Its design and characteristics were the same as XP1 above. It is possible that either shock or temperature, or both, unbonded the diaphragm thus breaking electrical continuity.

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1. W. L. Russell, Jr., Pulse Pressure Transducer — Design and Calibration, Lawrence Livermore Laboratory, Rept. UCRL-51844 (1975).

Summary

There are enough firsts among these measurements that one may well ask: what do they mean? We feel it is presumptuous to try to answer this with our limited data. However, several observations do seem possible.

Line-of-sight (LOS) pipes appear to behave very much like shock tubes. For example, if one allows for vaporized material, likely to be present in LOS pipes but quite unlikely in a shock tube, pressure measurements are analogous between the two systems. It seems reasonable, then, that such measurements infer something about total energy release in both systems. Furthermore, time of arrival at successive measuring stations can, with appropriate time resolution in the recording system, yield velocity-of-propagation information along with rate-of-attenuation information. Again, it seems to us that these data infer something about total energy release.

It is not so clear that temperature measurements reflect true gas temperature. Rather, they are currently thought to represent an interaction temperature between the sensor and the stream in which it is immersed. With the same time resolution constraints as for pressure, one can, however, get velocity-of-peak-temperature propagation, attenuation data, and some idea of the very high temperature (well above the capability of known thermocouples) that exists for a very short time. It seems that, theoretically at least, this should be related to known shock data.

Force measurements made in the pipe string itself clearly indicate that some portion of the total energy release is absorbed into the pipe walls. Series measurements at succeeding stations, i.e., across the bellows-slip joint section, indicate the shock mitigating effect of such an assembly. Those force measurements between the pipe and its support points are certainly of interest in any anchoring considerations. If, in addition, it is possible to correlate appropriate acceleration measurements with these force measurements, we are certain that no one denies the merit of good old $F = ma$.

We are very much encouraged by the results of this experiment. We believe these data comprise the best environmental measurements made to date. As such, they should be useful to the designers of experiments and those concerned with containment as well as those concerned with measurements.

Acknowledgments

We thank Thomas Boster and Leland Richards of L-Division Physics for allowing us to do the experiment and thank those that helped make it a success: Lee Loquist, Sam Powers, and the EG&G technicians for the electronic support; Ken Poor for helping us with the field operations; Gary Carter, Ethyl Clark,

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